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Energy Lab

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An Interactive Qualifying Project

A, B, & C Term – 2013-2014

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Part 1: Pedagogical Application to Energy Literacy

Abstract

This project incorporates several styles of laboratory pedagogy combined with the exploration of energy transfer and related energy functions and topics. A junior-senior level, undergraduate syllabus is created that encompasses seven energy experiments. Different combinations of laboratory pedagogy will be used for each lab to create an optimal learning experience for the students.

Introduction

Energy consumption rates are ever growing, in order to account for this increase in energy demands, technological improvements must be made to achieve efficiency with an end goal of sustainability. Energy awareness is not widespread; as a result there is a poor understanding of how energy is transferred. Promoting energy awareness through education is necessary to develop a considerable understanding of energy transfer among rising generations of scientists and engineers. The best way to accomplish effective education of energy topics is through the use of hands on laboratory experience. Exercising college course subject matter through real-world applications provides students with a holistic understanding of the material.

Several engineering programs in the United States offer courses that focus on energy transfer, however a select few of these courses rely on laboratory experimentation to effectively apply energy transfer concepts and equations to real world problems.

Worcester Polytechnic Institute does not currently offer an interactive course relating to energy. Although sustainability and environmental courses are available, they are strictly lecture based and do not allow for students to experiment with any of the energy topics covered in the class. This project aims to create a laboratory based college course for upperclassmen at WPI.

The syllabi for both an introductory and an intermediate level energy laboratory course will employ strategic use of laboratory teaching methods in order to provide upper level college students with a healthy knowledge of energy transfer. Beginning with simple chemical reactions and phasing into more complex biological and chemical systems; each lab will demonstrate transfer of energy from different sources and encourage the development of experimental procedures and laboratory skills.

Background

Many pedagogical techniques have been practiced and explored to date. Some instructional theories are best applied to different audiences and in different learning environments. Several laboratory techniques include Expository Instruction, Inquiry Instruction, Discovery Instruction, and Problem-Based Learning [2].

Expository Instruction is very structured, with preordained results. This approach will define exactly what it is that the students must do to familiarize themselves with the equipment and tools that will be used throughout the course [2]. This way, students will learn how to use lab equipment properly, allowing them to work more independently on future experiments.

Problem-Based Learning uses group work to encourage student collaboration, resulting in a better understanding of course material [2]. Group work prepares students for working in teams for future employers. This is also a way for more students to work with expensive instruments and materials throughout the class. Inquiry Instruction is less structured, and urges students to create their own procedure. Students are supplied with the necessary materials and information to complete the experiment, but have leeway in how they choose to solve the problem.

Discovery Instruction is the most free form approach to teaching a lab course, it involves a model or an outcome that the instructor has in mind but it is up to the students to design and evaluate the experiment themselves [2]. This style of laboratory intends to motivate students with curiosity in the subject and provides a deeper understanding of materials through independent research.

All seven of these labs require roughly fourteen weeks total to complete. Taking into account seven-week terms at WPI, this course would be best served as two courses, an introduction and an intermediate course.

There are a few courses offered by other colleges that have similar goals. Most similar, is *D-Lab Energy* offered by MIT [5]. This is a fourteen-week course that has a lecture and lab section. During the first seven weeks students are familiarized with energy topics in lecture and then have the opportunity to apply what they have learned in the lab. Using what was learned in the first seven weeks, students have the opportunity to travel to Nicaragua and El Salvador to find ideas for a final project concerning renewable energy solutions to local energy problems over their spring vacation. This course uses comparable teaching strategies, creating a structured lab environment for the first half of the course and then letting the students create and carryout their own energy project during the latter half.

Universities, such as Carnegie Mellon, RIT, DeVry, and others; serve similar courses. However, all of these courses have a strong lecture influence, where as our course encourages independent research. Suggested readings and out of class assignments will provide students with enough information to execute each lab, thus leaving more time for hands on experimentation.

Course Methodology

The experiments included in both syllabi were carefully selected to provide students with a well-rounded knowledge of energy conversion. Our decision to start with fossil fuels was supported by several ideals. Not only is fossil fuel combustion fairly well understood due to its common usage, but also a relatively simple topic to familiarize students to the laboratory with. Next, thermoelectric generation will involve more complex topics such as, heat transfer, thermodynamics, and thermo coupling. The photovoltaic lab was an obvious choice due to its rising popularity as a renewable energy source. This will include similarly complicated topics such as materials science and electrical engineering in relation to semiconductor materials and circuits. Wrapping up the introductory course with the biodiesel lab. This will be the most accelerated lab in the course. Encompassing similar topics as the fossil fuel experiment, however this time including the creation of biodiesel using microalgae. Biological applications will be presented in order to study biomass composition.

To start off the intermediate course, students will carry out preparations for the anaerobic digestion and biofuel experiments. This will give the students a chance to re-familiarize themselves with the laboratory and give time for the prepared mixtures to rest for several weeks before the experiments. The first full experiment will be the microbial fuel cell. This will take a considerable amount of time and involve some background research. Important topics include microorganisms, carbon oxygen demand, basic chemistry, and circuitry. By the end of the microbial fuel cell lab, the biofuel mash will be ready for experimentation. Students will learn about fermentation and cellulosic biomass conversion. Finally, the anaerobic digestion lab will be ready to carry out.

Students will learn more about fermentation through bacterial hydrolysis, acidogenic bacteria, and methanogens.

The introductory course will include, fossil fuel, thermoelectric Generation, photovoltaic, and biodiesel experiments. The fossil fuel lab will be the most structured experiment in order to familiarize students with proper laboratory and safety procedures. The students will be provided with explicit instructions and preordained results. This will prepare them for the less structured experiments to follow. Due to limited workstations for the thermoelectric generation, photovoltaic, and biodiesel labs, the students will separate into groups and alternate between the three labs. These three labs will encourage student collaboration through group work resulting in a better understanding of course material. Less explicit instructions and procedures will allow for some freedom as to how to design the experiment. Background information supplied by the professor will be necessary for the students to look over in order to conduct the experiments. A brief pre-lab assignment, including several extended response questions, will require an understanding of the background material. The complete course schedule is included in the Appendix A, Table 1.

The intermediate course will include, microbial fuel cell, biofuel, and anaerobic digestion experiments. The students will begin by preparing the materials for the biofuel and anaerobic digestion labs because it will take two weeks, and four weeks respectively for the combined ingredients to be ready for experimentation. During the waiting period for the biofuel lab, students will create their own microbial fuel cell. They will be provided with background reading, a model created by the professor, and the materials necessary. This is a free form approach to teaching a lab course, it involves a model that the instructor has in mind but it is up to the students to design and evaluate the experiment themselves. The biofuel and anaerobic digestion experiments will be carried out similarly. The curiosity of this style of laboratory will motivate the students and provide a deeper understanding through independent research. The complete course schedule is included in Appendix A, Table 2.

A couple of overarching energy themes will tie all of the laboratory experiments together; the first of which is energy density. This is best described as energy per unit volume. Calculating the energy density of multiple materials will allow someone to compare such materials to find the most efficient energy source. Leading into the second energy theme, efficiency. This is the ratio of energy input to energy output. Efficiency can be calculated in a number of ways. Each experiment will involve both energy density, and efficiency so that students can understand and compare the effectiveness of several distinctive energy sources in varying environments.

The careful selection of topics, teaching methods, and complexity, when combined, will create a learning environment for an upper-level, undergraduate, energy literacy course. Each of these experiments follow a trend of increased complexity and decreased procedural structure. These teaching methods will be beneficial to the students because they will not only prepare them for a professional laboratory experience, but also create an environment that will most influence the students to learn the material and understand it through physical manipulation of variables and observation. All this with the intent that the students will be more likely to retain what they have learned than they would have in a conventional energy lecture course.

Part 2: Lab Procedures and Experimental Outline

The Microbial Fuel Cell

Goal Statement

The purpose of this Microbial Fuel Cell Lab is to determine the efficiency of fuel cells as a function of fuel types, conductive solutions, and anode materials. Students will build fuel cells and measure the voltage across the fuel cell to calculate the cell's efficiency for different conditions, gaining familiarity with the following concepts as learning outcomes: relative energy density; energy transfer and conversion; resources, methods, and effectiveness; calculation and measurement of energy consumption and loss; basic lab procedures and system control. The experiment also utilizes appropriate pedagogical methodology to further reinforce the principles outlined above and to provide for a practical learning experience.

Introduction

This experiment integrates the concepts of biological, chemical, and physical energy conservation and conversion that are measured and calculated using relations between the fields of study. Anaerobic bacteria are harvested and used to chemically convert waste water into clean water and electrons, producing a voltage potential in a manner similar to that which is used in traditional hydrogen fuel cells. This output power is then measured using heat loss through a resistor and compared to theoretical calculations. For this lab, we chose to construct a two-chamber fuel cell, which employs one chamber of anaerobic digestion conducted by the bacteria and one chamber of clean water, electrolytic solutes, and oxygen flow. A salt bridge is used between the chambers to allow for the flow of excess hydrogen ions from the anaerobic chamber to the output chamber. An anode and a cathode are submerged in the anaerobic and oxygen flow chambers, respectively, which allows for the harvesting of electrons and the production of current flow and voltage potential. This process is outlined in the diagram shown below [3].

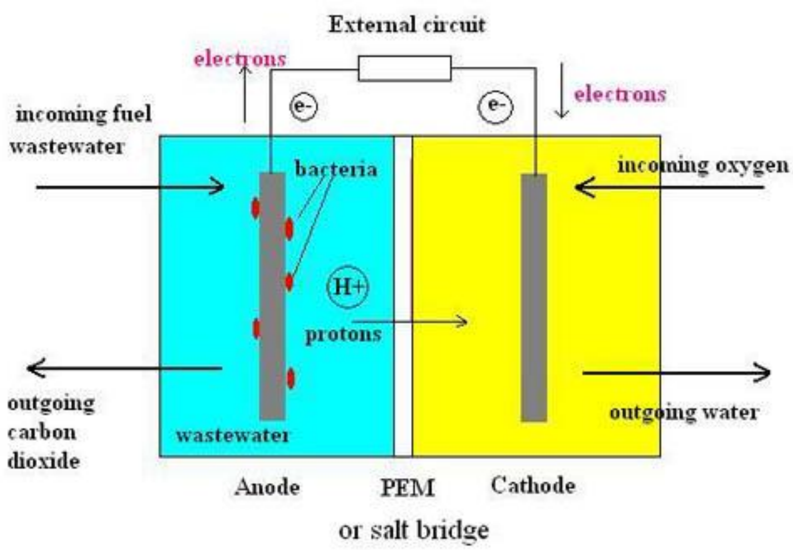

Figure 1: Basic Structure and Operation of a Microbial Fuel Cell (MFC)

Of course, with such a complicated process comes the need to employ many different relationships between processes in order to accurately assess the system quantitatively, the most significant being the relationship between the chemical reaction taking place and the number of electrons being produced over time as the reaction occurs. This is difficult to quantitatively apply to our system, as the cell's physical construction, the bacteria's content per unit volume, and the bacteria's energy conversion efficiency are widely variable depending on the quality of materials used and the type of anaerobic bacteria driving the cell. For this reason, the students will be asked to qualitatively analyze the cell in their labs while applying their knowledge of the energy conversion to the experiment. This will be done by altering the types of materials used in the cell (cathode material and shape, as well as anode material and shape) and understanding their effect on the system. The students will be required to have a firm grasp of what is occurring during the cell's operation; therefore, a quantitative assessment of the system is still a necessary component in this experiment.

Our quantitative assessment will consist of the applicable relations, measurements, and calculations as outlined in Bruce Logan's *Microbial Fuel Cells* [3]. The application of these quantities is used to determine the voltage output of the cell, which can be used to calculate the amount of power produced by our configuration. The equation to be used to represent the voltage potential is as follows:

$$E_{cell} = E_0 - \frac{RT}{nF} \ln\left(\frac{[products]^p}{[reactants]^r}\right)$$

This relation considers electromotive potential, temperature, and stoichiometric quantities that vary based on the type of reaction that takes place as well as atmospheric conditions. It will be discussed in more detail in the sections of this report that follow.

Logan's *Microbial Fuel Cells* provided us with the necessary understanding of the operation, design, and implementation of microbial fuel cells within the context of both research and practical applications. Using his methodology, combined with that of very helpful online resources, we were able to construct a microbial fuel cell using easily acquired materials that were used to demonstrate the basic operation of the cell.

Microbial fuel cells are being used in more practical applications today, mostly by industries whose waste can act as a rich fuel for this type of cell. Breweries, distilleries, waste treatment plants, and many others use microbial fuel cells to convert their waste into clean water in a way that can save on energy costs and help the environment. However, only industries whose fuel can be consumed by a specific type of bacteria can use this type of microbial fuel system; for example, the waste output of breweries contains yeast, which consumes glucose. In aerobic conditions (i.e. without the presence of an MFC), the yeast converts the glucose to carbon dioxide and water; conversely, in anaerobic conditions and as in the operation of an MFC, yeast converts glucose into carbon dioxide, hydrogen ions, and electrons, allowing for power generation [1]. These industries, when using this type of system, often chain together multiple cells to allow for higher volumetric waste consumption, more clean water output, improved efficiency, and increased power output [3].

It can be expected that microbial fuel cells do not exactly put out a high power output, mostly due to size limitations, bacterial efficiency and digestion time, and fuel/bacteria density. Other factors include the quality of the cathode and anode materials, which would ideally have very high carbon content and a maximized surface area. Large-scale MFC's are obviously much more practical, but for the purposes of testing and analysis we constructed a relatively small scale cell. A small MFC such as ours is likely to achieve a voltage drop of less than one volt. Thus, in our design we have incorporated our constraints and constructed the cell so as to provide somewhat accurate readings even with relatively small power outputs. As discussed earlier, the experiment the students will conduct will be based upon qualitative assessment of the cell through manipulation of variables such as anode and cathode materials, and the microbial fuel samples. This quantitative assessment of the combinations of materials used in correlation with voltage measurements will be used to provide an adequate understanding of the cell's operation for the students.

Background & Literature Review

In this section, we will detail the operation of a microbial fuel cell, both in ideal situations and in the conditions that apply to the construction and operation of our particular fuel cell. This includes the chemical/bacterial components, the cell's electrical operation and efficiency, and the overall input/output of the cell, along with a general time factor analysis. We will also discuss Bruce Logan's *Microbial Fuel Cells*, as well as other references used, and how they pertain to the cell's design and our experimental procedure.

The basic operation of a microbial fuel cell, as described above, involves the input of a fuel (usually a waste of some kind in liquid form) that can be broken down and consumed by the chosen bacteria. This fuel must contain a sugar in some form, the easiest to obtain being glucose. These components are housed in one chamber of the cell and deprived of oxygen so as to allow for anaerobic digestion and subsequently the production of protons and electrons as opposed to excess water. Also in this chamber is a carbon-rich anode, to which the electrons are drawn. This, in part, creates the voltage potential necessary for power output. The second chamber (attached by a salt bridge that allows protons to pass through it) contains water and oxygen gas, as well as the cathode of similar construction to the anode. Hydrogen ions (protons) pass from the anode chamber to the cathode chamber my means of the salt bridge and attract to the negatively charged cathode, which is connected externally to the anode with a small resistance between them. This completes the circuit, allowing for the production of a voltage which can be measured across the resistor and used in the calculation of power output via Joule's law and Ohm's law.

In order to fully understand how the cell works, we must go into detail on the biological and chemical components of its operation. To do this, we must examine the stoichiometric relationships between the fuel of the cell and its products. Here, we can assume that glucose and water are present in the anode chamber and that they are reacting anaerobically due to the bacterial catalyst. The products of this reaction are carbon dioxide, protons, and electrons. This reaction, taking place entirely in the anode chamber, can be represented as follows:

$$C_6H_{12}O_6 + \mathbf{6}O_2 \rightarrow \mathbf{6}CO_2 + \mathbf{6}H_2O$$

This reaction represents the full balance of all substances involved in the production of power in the cell. For our application, two separate reactions are taking place in the two chambers of the cell: in the anode chamber, sugars and water are provided (within the waste water) in contact with the bacteria and produce hydrogen ions (protons), electrons, and carbon dioxide; in the cathode chamber, oxygen reacts with the hydrogen ions (which pass through the mediator between the chambers) and the electrons (flowing through the cell circuit) to produce water. These reactions, respectively, are represented below:

$$C_6H_{12}O_6 + \mathbf{6}H_2O \rightarrow \mathbf{6}CO_2 + \mathbf{24}H^+ + \mathbf{24}e^- \text{ (anode)}$$

$$\mathbf{6}O_2 + \mathbf{24}H^+ + \mathbf{24}e^- \rightarrow \mathbf{12}H_2O \text{ (cathode)}$$

These reactions take place sequentially, and therefore can be combined to form our first reaction balance. These reactions, combined with Table 3.1 in Logan's *Microbial Fuel Cells*, can be used to determine the reaction coefficient and values for E0 and n to find the theoretical operating electrical potential produced by the microbial fuel cell. To recall from the previous section, the equation to be utilized to calculate the produced electric potential is

$$E_{cell} = E_0 - \frac{RT}{nF}\ln\left(\frac{[products]^p}{[reactants]^r}\right)$$

In this relationship, R is the ideal gas constant, T is the cell's operating temperature, n is the number of electrons being transferred (based on the reaction), and F is Faraday's Constant. The ratio displayed indicates the cell's reaction quotient, determined in Table 3.1 of *Microbial Fuel Cells* based on the reaction. E_0 is the standard cell electromotive force of the system, where

$$E_0 = E_0(cathode) - E_0(anode)$$

This theoretical output voltage will be determined by the students before the experiment in order for them to develop a hypothesis of their system, and so that it can be used in post-experiment analysis [3].

Ideally, materials for the fuel cell would be chosen so as to allow for adequate observation of the processes occurring within the cell while also minimizing heat loss and maximizing bacterial catalysis to produce the highest voltage possible and maximize efficiency. Thus, a transparent insulating glass or polymer would be ideal for the chamber housing to minimize energy loss and ensure proper operation. A material of high carbon content and surface area would allow for maximum electron absorption by the electrodes, and a high-density bacterial sample (reacting with a fuel of high sugar content) would catalyze the reaction quicker and with a higher proton/electron output. In addition, a pure oxygen gas input to the cathode chamber, rather than an air bubbler or similar mechanism, would allow for a more efficient reaction provided that the oxygen input could be precisely controlled. Despite all of these idealized factors, the fuel cell we constructed for experimental purposes, as well as the cells that will be used by the students, will surely be far less than ideal. For our purposes, we built a crude microbial fuel cell using plastic bottles as reaction chambers, easily-acquirable materials of varying shapes and carbon content for electrodes, and a bacteria/fuel sample from a local pond. Even using such materials, we were able to obtain more than satisfactory results for our output voltage, which changed based on the variety of electrode materials we chose.

Overall, with the chosen design and procedures, the students should be able to qualitatively assess the operation of each of their microbial fuel cells while gaining a quantitative understanding of the system. This will support the intended learning goals outlined previously as well as introducing modern systems and capabilities that are relevant to real world applications.

Methodology of the Experiment

In researching the design and implementation of microbial fuel cells we were able to design an experimental lab course to demonstrate and assess the operation of such a system as part of the curriculum of an energy lab course. This lab course in particular employs a specific experiment in which students will analyze and take measurements on the operation of their own microbial fuel cells, which will be built by the lab assistants prior to student use. Through the material outlined in the previous section, we were able to determine the necessary components and relationships for this lab experiment.

We first analyzed the teaching strategies that were applicable to experimental lab courses and implemented many of our research findings into the design of the class itself. Next, we decided to build and analyze a microbial fuel cell ourselves. In doing so, we were able to gain an understanding of what was absolutely necessary in building and maintaining a working cell while also gaining practical expectations on the output of the cell and how it could be measured. Again, as the assessments the students will be making will be qualitative, it is not necessary to apply quantitative relationships in order to explain the cell's operation. Rather, the students will alter key components of the cell and gain on understanding of the alterations' effects on the cells.

The construction of the cell, albeit somewhat crude, allowed us to understand the minimum requirements of its operation and put the feasibility of its construction into perspective. For each of the chamber vessels, we chose two 500 mL plastic bottles that were square in shape. The square shaped bottle is optimal for when it comes time to connect the two chambers with the salt bridge. We cut a ¾ inch hole in the side of each bottle at approximately 2 and ½ inches from the bottom of the bottle, where the PVC couplings will be hot glued into the bottles. Also, a small hole must be drilled into the top of each bottle cap for the anode and cathode wires. One bottle will also require a larger hole for the air pump tube to enter the bottle.

For the salt bridge we used a 3-inch length, ¾ inch diameter, PVC nipple; both ends screwed into each of the two ¾ inch, threaded PVC couplings glued to the bottles already. The material inside of the salt bridge is comprised of vegetable agar, water, and iodized table salt. Fifteen grams of salt mixed with three grams of vegetable agar in 150 mL of water will be more than enough to fill the tube. We stirred the agar and salt in the water over high heat until the salt was dissolved and the water began to boil. We then poured this mixture into the PVC tube and refrigerated until the mixture became solid. The agar-salt mixture will be held inside the tube with thin nylon mesh material placed over the ends of the PVC nipple before screwing it into the couplings.

Next, we chose to make two sets of anodes and cathodes. The first anode and cathode were comprised of carbon paper and aluminum wire, by folding the carbon paper into a shape that had a high surface area and wrapping it with aluminum mesh and connecting aluminum wire to the end. The second anode and cathode were made of graphite rods and aluminum wire, similarly wrapping the graphite rods with aluminum mesh and connecting aluminum wire to each. Students are likely to notice differences in the voltage drop across the cell from anode to anode or from cathode to cathode.

With the microbial fuel cell mostly assembled, we obtained and prepared the fluids that filled each side of the chamber. The anaerobic chamber required the microbial fuel; we chose mud obtained from the benthic zone, where microbes have little access to oxygen. The benthic zone is the lowest level in a body of water. Our sample was taken from the floor of a pond, at a depth of three feet below the surface. For the aerobic chamber, we used a salt-water mixture by heating 500 mL of water with 200 grams of salt, stirring often until the salt is fully dissolved.

To complete the assembly of the microbial fuel cell, we lowered the anode and cathode into each chamber and fed the wire through the small holes in the caps. Similarly we fed the tube for the water pump through the aerobic chamber cap, and attached the stone diffuser to the end of the hose. Before capping the chambers, the anaerobic side was filled with the microbial mud and the aerobic chamber with the salt solution. Finally, the chambers were capped and the two wires were led from the anode chamber and cathode chamber to measure a voltage difference using a multireader.

Students will be introduced to the microbial fuel cell with a model provided by the instructor, who will demonstrate its operation. The students will be provided with a reading assignment including excerpts from *Microbial Fuel Cells* [3]. The readings will serve as the background research for the assignment and will be done outside of class before beginning the experiment. With an understanding of the background research, the students will be provided with a number of different materials to create their own microbial fuel cells. All of the air pump supplies, fuel cell chamber containers, wires, and salt bridge materials will be comparable. However, there will be several materials available for the students to make their own anodes and cathodes. These materials will include, carbon paper, carbon cloth, graphite rods and plates, and conductive mesh. Using their knowledge of optimal anode and cathode construction they will make two sets of anodes and cathodes. After completing the construction of the fuel cell, students will test each cell multiple times, using the different anodes and cathodes that they made. They must then record the voltage differences across the two chambers using a voltmeter for each set of anodes and cathodes. The voltage differences will likely differ from design to design of the anodes and cathodes.

The fuels will have different chemical oxygen demands due to bacteria per unit volume. The conductive solutions in the aerobic chamber will alter the conductivity within the circuit. Finally, changing the anode material will affect how well the bacteria are attracted to it. Measurement of voltage will result in a value of loss over the circuit by differentiating the measured value with the theoretical value. Altering the variables with result in a change in loss over the circuit; thus, the variables can be assessed qualitatively by analyzing experimental data.

After the experiment has been completed, the students will be asked to exhibit what they have learned about the cell's operation by answering questions similar or equivalent to the following:

- How is this cell's operation similar or different from the operation of other fuel cells you have seen?
- How can the cell's design be improved to maximize power output?
- What future applications could this cell be a part of?

Adequate understanding of the cell will allow students to confidently apply these concepts to real world applications and will be assessed based on the answers to questions like these.

Conclusion

Using our research of laboratory teaching methods and pedagogical theories we have developed curricula for an introductory and an intermediate level energy literacy course. By carefully selecting combinations of teaching methods relevant to laboratory courses, we were able to create an optimal learning environment for the students. By introducing students to the laboratory with a structured agenda they can become familiar with experimental procedures, effectively preparing them for future experiments with less structure. Ultimately, encouraging independent research and student collaboration through group work will prepare them for a professional laboratory environment.

Through our understanding, construction, and analysis of microbial fuel cells, along with the use of Bruce Logan's *Microbial Fuel Cells* [3], we were able to synthesize a lab-based experimental course supplement that will provide students with an understanding of the processes and variables associated with microbial fuel cells. In addition, this experiment will supplement the desired learning outcomes and overall objectives associated with a lab-based energy course, along with many other energy-related experiments. Our hope is that at some point in the near future, this course, or a course similar to it, will become a part of the WPI curriculum to educate students on the importance of energy transfer and clean energy development.

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Appendix A, Course Schedules:

Table 1 Introductory Course Schedule

Week	Class	
	1	2
1	Course Overview	Begin Fossil Fuel Lab
2	Continue Fossil Fuel Lab	Finish Fossil Fuel Lab
3	Begin Thermoelectric Generation Lab	Continue Thermoelectric Generation
4	Continue Thermoelectric Generation	Continue Thermoelectric Generation
5	Begin Photovoltaic Lab	Finish Photovoltaic Lab
6	Begin Biodiesel Lab	Continue Biodiesel Lab
7	Finish Biodiesel Lab	Course Conclusion

Table 2 Intermediate Course Schedule

Week	Class	
	1	2
1	Course Overview	Prepare Anaerobic Digestion Mash
2	Prepare Biofuel Mash	Begin Microbial Fuel Cell Lab
3	Continue Microbial Fuel Cell Lab	Continue Microbial Fuel Cell Lab
4	Finish Microbial Fuel Cell Lab	Begin Biofuel Lab
5	Continue Biofuel Lab	Finish Biofuel Lab
6	Begin Anaerobic Digestion Lab	Continue Anaerobic Digestion Lab
7	Finish Anaerobic Digestion Lab	Course Conclusion

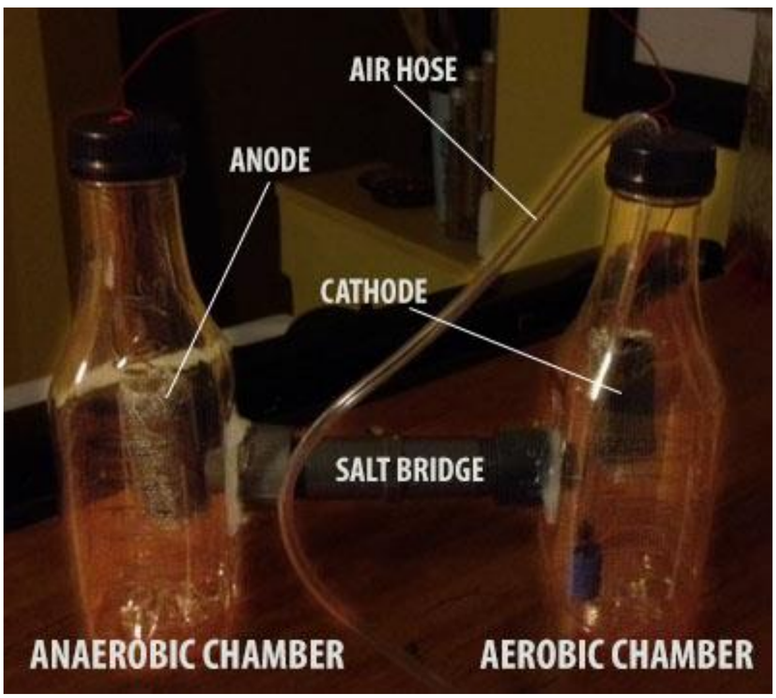
Appendix B, Raw Data:

Voltage difference across MFC using carbon paper anode and cathode: 0.095 Volts

Voltage difference across MFC using graphite rod anode and cathode: 0.302 Volts

Appendix C, Our Fuel Cell:

Figure 2: Completed Microbial Fuel Cell (MFC)



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